ONSHORE SPILL MODELLING TO INFORM CONTINGENCY PLANNING

INTRODUCTION

Onshore oil spill modelling can be used to inform contingency and response plans for up and down stream hydrocarbon facilities. By undertaking numerical modelling the theoretical spill scenarios can be assessed in detail to catalogue the worst creditable cases in terms of health, safety and environmental risk. Response or mitigation strategies can then focus on priority locations and infrastructure and allow increased confidence from operators and regulators. This approach has the potential to reduce uncertainties, eliminate hazards and engineer economic and robust contingency plans.

This paper presents a case study for a confidential project recently undertaken by WorleyParsons. It represents a transferable approach which could be applied to other major projects or scaled to fit smaller projects for liability management or contingency planning purposes.

BACKGROUND

WorleyParsons has recently undertaken an Oil Spill Identification and Assessment study for a new upstream development in the Middle East. The project was performed to comply with the client’s company policy, international best practice and the local regulatory requirements. The assessment drew on traditional approaches for contaminated land risk assessment as well as flood modelling techniques.

This assessment was undertaken as part of the Front End Engineering Design (FEED) phase of the project and was completed in close liaison with the project engineering teams.

The project required the construction of more than 200 gathering wells, 500km of above and below ground pipelines with varying diameters and pressures, a large central processing facility with associated storage tanks and several produced water disposal wells.

The site was located in a virgin arid environment with no permanent surface water features but two large wadi...
channel systems capable of sustaining limited vegetation and grazing rights for nomadic bedhu communities. The limited groundwater resources at the site were occasionally used by local communities and by neighbouring hydrocarbon developments.

Based on the scale of the project it was recognised at an early stage that the number and type of possible hydrocarbon release scenarios was going to be very high and spread across a large geographical area with varying environmental and socio-economic sensitivity.

Literature searches and discussion with the client at the outset of the project had identified limited guidance for onshore spill modelling and limited examples of similar projects. In addition no specific modelling packages were commercially available and it was evident that different tools would be required to represent the different flow and transport mechanisms.

On this basis, the project team recommended that a phased, risk based approach utilising expertise from their hydrocarbons engineering colleagues would be the most suitable and economic approach followed by detailed bespoke modelling for the worst credible case scenarios using commercially available surface and subsurface flow models. The assessment phases are summarised below.

1. **Spill Identification using Engineering Knowledge**

A series of workshops were organised with the client to establish the oil spill planning scenarios for the project up to and including the worst credible case.

The workshops involved a range of engineering disciplines including reservoir engineers, well engineers, process engineers, pipeline engineers, pipeline integrity specialists, civil engineers and logistical planners as well environmental, GIS and scientific specialists.

The outcome of the workshops was to produce a detailed matrix of all possible oil spill planning scenarios based on the:

- location (geographical and number of locations)
- type of infrastructure at each location (e.g. tank, pipeline, pump, well, mud-pit, above or below ground features etc.)
- the release method (e.g. tank and bund failure, pipeline leak or full bore release)
- the type of hydrocarbon product (including produced water)
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Table 1 - Example of oil spill planning scenarios

<table>
<thead>
<tr>
<th>NO.</th>
<th>SOURCE</th>
<th>TYPE OF RELEASE</th>
<th>COMPOUND</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Well pads</td>
<td>a) Well blow out</td>
<td>Hydrocarbon product</td>
</tr>
<tr>
<td></td>
<td></td>
<td>b) Tank spill/bund failure</td>
<td>Diesel</td>
</tr>
<tr>
<td></td>
<td></td>
<td>c) Mud pit leak</td>
<td>Oil based mud (OBM)</td>
</tr>
<tr>
<td>2</td>
<td>Well injection pads (above ground)</td>
<td>a) Pipeline failure</td>
<td>Produced water</td>
</tr>
<tr>
<td></td>
<td></td>
<td>b) Pipeline leak</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Mud Pits</td>
<td>a) Pipeline leak</td>
<td>Produced water</td>
</tr>
<tr>
<td></td>
<td></td>
<td>b) Pipeline failure</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Liquid Mud Pits</td>
<td>a) Pipeline leak</td>
<td>Produced water</td>
</tr>
<tr>
<td></td>
<td></td>
<td>b) Pipeline failure</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Export pipeline (above ground)</td>
<td>a) Pipeline leak</td>
<td>Hydrocarbon product</td>
</tr>
<tr>
<td></td>
<td></td>
<td>b) Pipeline failure</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Export pipeline (below ground)</td>
<td>a) Pipeline leak</td>
<td>Hydrocarbon product</td>
</tr>
<tr>
<td></td>
<td></td>
<td>b) Pipeline failure</td>
<td></td>
</tr>
</tbody>
</table>

The sensitive environment features and the key hydrocarbon infrastructure were uploaded to the project GIS to illustrate the interaction between the project and its environment. Plans of the key project areas were produced and the possible receptors added to the oil spill planning matrix.

3. Spill Screening Assessment

An initial risk screening exercise was performed using qualitative and quantitative risk prioritisation and GIS tools to estimate the potential geographical and hydrogeological impact from the identified oil spill planning scenarios.

A series of conceptual spill models were developed to characterise the key source, pathway and receptor linkages. An example is presented in Figure 2.

The spill scenarios were each assessed independently. No assessment of likelihood or probability of each scenario was included in this assessment.

The screening phase included:

- The flow rates and total spill volumes for each spill scenario were calculated based on information provided by the engineering teams and entered into a spreadsheet model.
- A multi-scenario spreadsheet model was used to estimate the possible geographical spread of hydrocarbons, taking into account simple surface topographies and estimated pooling depth based on the terrain.
- These results were used to estimate maximum longitudinal and lateral distance of surface spreading at each location (note: the model would estimate the volume of surface water impacted any spills interacting with the surface spill if surface waters were present).
- The potential vertical migration of hydrocarbon product through the subsoil was also estimated for all the spill scenarios. The results were compared to the groundwater conditions within the vicinity of the project area.

2. Desk Study

Literature searches were undertaken to characterise the environmental and socio-economic sensitivities which could be impacted by a spill event. For this project, the main sources of information related to the project Environmental and Social Impact Assessment (ESIA) and associated environmental field studies. Additional sources of information included the project flood risk assessment and scour assessment and publicly available information on ground and groundwater conditions within the vicinity of the project area.
elevations across the site to assess whether groundwater resources were at risk from each spill scenario. Where modelling indicated a potential impact on groundwater resources, the volumes or impacted groundwater and groundwater plume dimensions were calculated using traditional flow and transport equations.

• GIS was used to plot the maximum estimated spreading distances from each spill centre and to highlight the spill locations with the potential to impact on sensitive receptors.

The results of the risk screening were used to screen out those spills which were generally small scale, unlikely to impact sensitive socio-environmental receptors or could be dealt with using local or non-specialist response equipment (as ‘business as usual’). Those spills which were considered to have a larger or direct impact to environmental or socio-economic receptors were highlighted in the oil spill planning matrix and were considered to need more detailed assessment to inform the contingency and response planning.

4. Detailed Spill Modelling Assessment

Detailed modelling was undertaken on a subset of the largest spills from the oil spill planning scenario matrix to better define the geographical and time dependant spreading of the spills.

The spills taken forward to detailed modelling included failure of high pressure gathering pipelines and process water reinjection pipelines, which were shown to have large release volumes, and possible impacts on environmentally sensitive areas, as well as smaller spills and undetected leaks from tanks and mud-pits directly within environmental sensitive area (such as wadi channels and agricultural areas with groundwater dependant users) which may not have otherwise have been considered as significant risks.

Detailed modelling was undertaken by hydrology and hydrogeological experts to produce plans and animations of spill migration with time, ranges of spill pooling depths, assessment of migration depth of hydrocarbons through the subsurface.

Overland flow modelling was undertaken using the commercially available TuFlow package and a digital elevation model (DEM) to represent the surface flow,
TuFlow is a 2D surface flow modelling package approved by the Environment Agency (UK) and FEMA (USA) which solves the depth averaged 2D shallow water equations (SWE). The SWE are the equations of fluid motion used for modelling long waves such as floods used to accurately predict flow paths and extents over complicated (variable) ground terrain.

Minor adjustment to the model files can allow non-aqueous fluids to be modelled by accounting for differences in density, viscosity and internal eddy friction. An example of the model output is presented in Figure 3.

Impacts to groundwater were modelled using the Hydrocarbon Spill Screening Model (HSSM) developed by United States Environment Protection Agency (US EPA) and the Environmental and Water Resources Engineering department at the University of Texas.

The model is intended for the simulation of subsurface releases of non-aqueous phase liquids. The model consists of separate modules for flow vertically through the vadose zone, spreading in the capillary fringe, and transport of chemical constituents in groundwater. These modules are based on simplified conceptualisations of the geological and hydrological properties of the ground.

HSSM was used to simulate the migration of hydrocarbons through the unsaturated zone from pools of hydrocarbons (in and outside of bunds) and from below ground leaks from mud-pits and pipelines.

A key aspect of the modelling was to include a sensitivity and uncertainty analysis. For each input parameter used in the detailed modelling a range of plausible minimum and maximum values was used to ascertain the sensitivity of each parameter and to estimate the upper and lower bounds of the spill migration. In some instances, especially for the below ground impacts, this resulted in large ranges in
the results which led to further research to better define the input parameters and conceptual spill model.

Following the modelling, refined GIS plans were produced to present the assets (well, pipeline and facility locations) which could impact on sensitive environmental receptors and could require specialist or rapid response planning. In addition plans and animations of the individual spill events were produced to demonstrate the model results to the client and project team.

RESULTS

The results of the assessment included:

• The location of the worst credible spill scenarios.
• The geographical area and volume of potential impact.
• The migration depth of hydrocarbon products in the subsurface and likely impact on groundwater resources.
• Plots and tables of migration vs. time for surface spreading and subsurface migration with upper, lower and most likely curves to inform response planning.

All the information collected as part of the assessment was summarised in the original oil spill planning matrix to document a transparent and auditable record of the spill scenarios, source references and results.

As the assessment was undertaken during the design phase of the project the spill assessment and liaison with the engineering teams enabled mitigation measures to be included into the design, including removal of key infrastructure away from environmentally sensitive areas where possible.

SUMMARY

This case study presents an example approach for assessing onshore hydrocarbon spills using engineering and environmental specialists. A summary of the findings and lessons learned from the project are presented below:

• Limited guidance or information or approaches to onshore spill modelling is publicly available. No one modelling package was commercially available to address all the scenarios considered in this assessment.
• The initial workshop process is important to formulate and agree the oil spill planning scenarios to be taken forward in the assessment.